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Study of X-Ray Surface Back Diffraction. Recording of a Diffracted Beam

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In the previous work /1/ we have studied experimentally the effect of an X-ray surface back diffraction (SBD) for a transmitted beam. It has been shown that in the first approximation the experimental results are satisfactorily explained by the two-wave theory of dynamical diffraction.

In the present note for the first time the features of SBD for a back diffracted beam (BDB) are studied. As it was stated in /1/, these features represent their own interest.

Experimental measurements are compared with a more exact four-wave dynamical diffraction theory. As it was first mentioned in /2/, most of back reflections are multiwave owing to the fact that the reciprocal lattice vector, corresponding to the back diffraction, is the diameter of the Ewald sphere. In particular, SBD on (620) planes studied in our experiment is a four-wave one with the excitation of additional (440) and ($2\bar{2}0$) reflections. The detailed analysis of the four-wave SBD, made in /3/, showed that multiwave effects occur on SBD curves within a very narrow angular region about the centre: $|\delta\Theta_{\parallel}| \leqq 10^{-5}$ to 10^{-6} rad. On the other hand, the multiwave dips on the SBD curves may serve as a precise origin for an angular matching of them.

In recording of BDB two additional difficulties exist, requiring perfection on the experimental set-up, in comparison with /1/. In the first place, it is necessary to separate the BDB from the incident one, because they propagate along one line in opposite directions. For this purpose the idea realized in /4/ was used for recording of a back diffraction in the Bragg geometry. In a crystal-monochromator 3 (see Fig. 1) a semitransparent window 1.5×1.5 cm^2 in dimensions and $\approx$ 15 μm thick was etched. The incident beam was Bragg reflected from the window surface, and the BDB passed through the window with a $\approx$ twofold attenuation of its intensity, with the exception of a very narrow angular band of a strict scattering

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backward: $|\delta\Theta_{\parallel}| \leq 5''$, in which this beam also fulfilled the Bragg condition for a crystal-monochromator.

The second difficulty consists in the fact that it is nessecary to separate the surface BDB from the beam, back diffracted in Bragg geometry on a lateral face of the sample. To solve this problem, a vertical arranged position sensitive detector (PSD) was applied. Separation was based on the difference in exit angles of the beams. The first BDB (surface) had an exit angle Φ_h, and the second one $-\Phi_o$. Hence, the angle between the beams was equal to $\Phi_o + \Phi_h$. In the experiment the incidence angle was chosen to be $\phi_o = 21'$ and the beams diverged on the PSD rule by $\approx$ 2 to 4 mm.

The SBD measurements were made on reflection of $CoK_{\alpha 1}$ radiation from (620) planes of a Ge crystal with (110) surface orientation. The scheme alignment was analogous to /1/ through the coincidence of the additional reflexes (440) and $(2\bar{2}0)$. Then by means of scanning along the $CoK_{\alpha 1}$ line through the stepwise turning of the crystal-monochromator 3 different values of the back diffraction parameter $\varepsilon = 1 - \lambda/2d$ were specified.

Experimental rocking curves of BDB depending on the $\delta\Theta_{\parallel}$ angle are given on the left side of Fig. 2. The dashed lines represent corresponding theoretical curves for the ideal crystal, computed on the basis of the four-wave dynamical diffraction theory. The ε values, used in computations, were estimated through

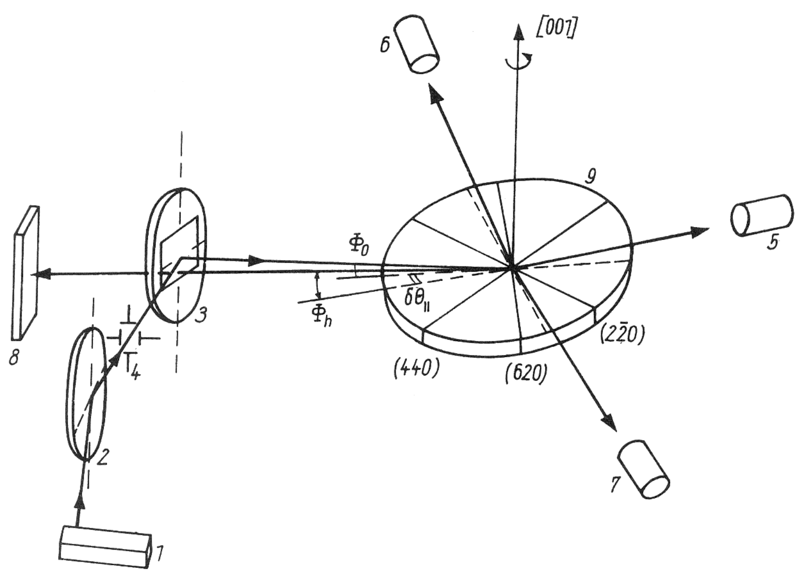

Fig. 1. Experimental layout (1 source, 2 first monochromator, 3 second monochromator containing a semitransparent window, 4 vertical and horizontal slits, 5, 6, 7 counters for transmitted and additional diffracted beams, 8 position sensitive detector for the back diffracted beam, 9 sample)

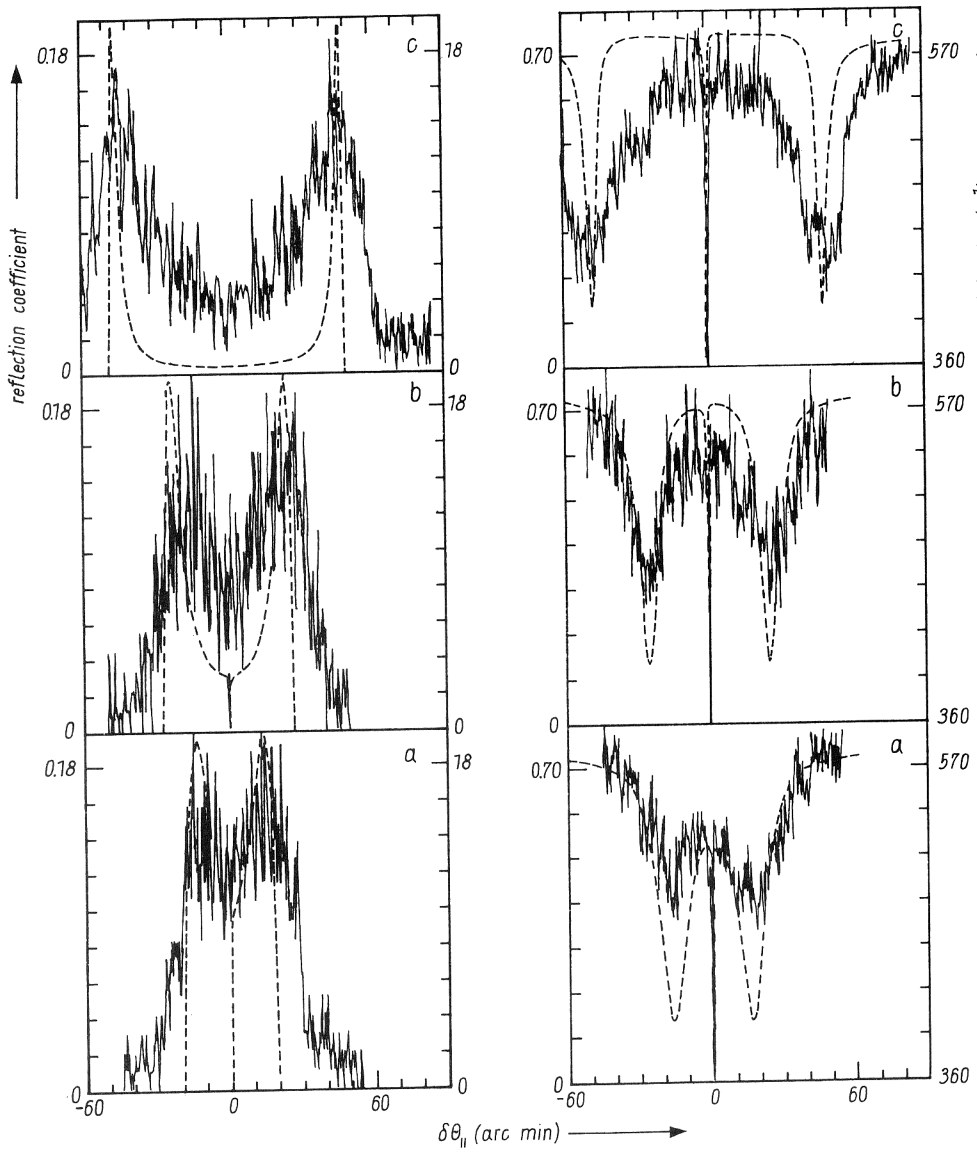

Fig. 2. Dependence of the intensity of back diffracted (left side) and transmitted (right side) beams on the scanning angle of a sample around the [001] axis for different ε values. Measurements made at (620) reflection of $CoK_{\alpha 1}$ radiation from a Ge crystal. The dashed lines show corresponding theoretical curves computed for an ideal crystal in the four-wave approximation with the following parameters: $\phi_o = 21'$, $\phi = 0$, ε = a) 2.5×10^{-5}, b) 4×10^{-5}, c) 11×10^{-5}

the angular distance between the valleys on the rocking curves of the transmitted (specularly reflected) beam (right side of Fig. 2). The angular matching of the theory with experiment was carried out according to the superposition of multiwave dips at the transmitted beam rocking curves. When matching the curves on the right side of Fig. 2 according to the intensity scale, the tails and the minimum of the multiwave dips were brought into coincidence. The large background of ≈ 360 pulses/s on the experimental specular reflection curves is attributed to the fact that a portion of an incident beam strikes the counter 5 passing by the sample.

The fine structure of the multiwave region was not resolved in the experiment. Therefore the rocking curves of additional reflexes are not of interest and so are not shown.

A qualitative agreement of theory with experiment is observed. Since a high experimental resolution is demonstrated by means of a narrow multiwave dip, the considerable broadening of the experimental curves in comparison with theoretical ones is due to the spread of the interplanar spacing in the crystal surface layer ≈ 10 nm deep, in which surface diffraction beams are formed.

The most interesting theoretical prediction for the BDB is the following dependence of its exit angle with respect to a crystal surface on the diffraction conditions:

$$\Phi_h^2 = 2(2\varepsilon + \phi^2) - \Phi_o^2 - 2\,\delta\Theta_\parallel^2 \quad . \tag{1}$$

Here ϕ is the angle of misorientation of diffracting planes with respect to the surface normal of the crystal; the other angles are shown in Fig. 1. As follows from (1), when scanning along $\delta\Theta_\parallel$ (and also along Φ_o), the BDB rocking curves should have rigid angular limits. Beyond this limit the back diffracted intensity in vacuum is absent owing to the effect of total internal reflection of the diffracted wave in the crystal, being the consequence of a change of the dispersion law under conditions of the dynamical Bragg diffraction. The absence of tails despite the broadening of the experimental curves on the left side of Fig. 2 confirms the mentioned effect. The additional indirect confirmation of the effect was also a decrease of the Φ_h angle of the BDB exit, when $|\delta\Theta_\parallel|$ increased, which was recorded by the PSD.

We think that the experimental proved effect of the "ring" total internal reflection for the diffracted beam in the surface back diffraction geometry may find useful applications in synchrotron radiation optics.

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